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A Biophysical Model for Estimating Site Index for the Major Commercial Tree Species in British Columbia

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Gordon Nigh

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ABSTRACT

A site index geographic information system (GIS) layer is being developed for British Columbia so that estimated site indices are available for the major commercial tree species across their ranges. The Site Index – Biogeoclimatic Ecosystem Classification (SIBEC)/predictive ecosystem map (PEM)/terrestrial ecosystem map (TEM) method will be used to populate the layer with site index by species. However, there will be gaps in the layer where there are no PEM/TEM or SIBEC data. The biophysical models resulting from this project will be used to fill these gaps. They predict, by species, site index from biogeoclimatic zone, slope, aspect, elevation, and climate variables. Data for these models come from the SIBEC project and various Site Index Adjustment projects. The climate variables are predicted from the ClimateWNA model. A biophysical model was fit separately for the following species: trembling aspen (*Populus tremuloides*), amabilis fir (*Abies amabilis*), subalpine fir (*Abies lasiocarpa*), western redcedar (*Thuja plicata*, coastal and interior), paper birch (*Betula papyrifera*), Douglas-fir (*Pseudotsuga menziesii*, coastal and interior), western hemlock (*Tsuga heterophylla*, coastal and interior), western larch (*Larix occidentalis*), lodgepole pine (*Pinus contorta*), ponderosa pine (*Pinus ponderosa*), black spruce (*Picea mariana*), Engelmann spruce (*Picea engelmannii*), Sitka spruce (*Picea sitchensis*), white spruce (*Picea glauca*), and interior spruce (white spruce, Engelmann spruce, or their cross). When compared to benchmark models, the biophysical models performed about as well as the benchmark except for the models for coastal western redcedar, coastal Douglas-fir, coastal western hemlock, Sitka spruce, and paper birch.

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INTRODUCTION

The Site Index – Biogeoclimatic Ecosystem Classification (SIBEC) model is commonly used to obtain site index estimates for the major commercial tree species in British Columbia (Mah and Nigh 2003; British Columbia Ministry of Forests and Range 2011). The model consists of a look-up table with entries for tree species and ecosystem type. The ecosystem is classified according to the Biogeoclimatic Ecosystem Classification (BEC) system into a zone, subzone, subzone variant (note that not all subzones have variants), and site series (Meidinger and Pojar 1991). The SIBEC model is derived by establishing sample plots, classifying the ecosystem for the plots, and estimating the site index from the site tree(s) on the plot. Second-approximation site index estimates are derived by averaging the site indices for each unique species/site series combination, which become the site index estimate for that combination of species and site series. First-approximation site index estimates, which are being phased out as more data are collected, were derived through a regression analysis (Mah and Nigh 2003). The predicted site indices from the regression analysis were placed into classes, and the midpoint of the class became the first-approximation site index estimate for the site series/species combination.

The application of the SIBEC model requires information on both the BEC site series for the area of interest and the tree species on the site (or the species that will be regenerated on the site). The site index for the site is then predicted by the SIBEC model using the site series and species as entries into the model. Obtaining the site series is commonly done in one of two ways: by conducting a ground survey for site series or by using a predictive ecosystem map (PEM)/terrestrial ecosystem map (TEM) (British Columbia Ministry of Environment 2012). Determining the site series can be a problem if the area of interest is too large to do a ground survey and a PEM/TEM is not available. The purpose of this project is to develop a biophysical site index model that requires readily available biophysical input variables to make site index estimates. The biophysical models will be suitable for strategic planning purposes where the SIBEC/PEM/TEM approach cannot be used. The results will be incorporated into a site index GIS layer to make the results readily available. At the time of writing, a preliminary site index layer had been published at www.for.gov.bc.ca/hts/siteprod/provlayer.html. The Forest Analysis and Inventory Branch of the British Columbia Ministry of Forests, Lands and Natural Resource Operations is planning to do a comparison between this site index layer and additional data that are becoming available, and to pilot the layer in the Robson Valley Timber Supply Review.

DATA

The data for this project come from two sources: the SIBEC project and Site Index Adjustment (SIA) projects.

The SIBEC data were collected following SIBEC sampling protocols, which are documented at www.for.gov.bc.ca/hre/sibec/documents/standards.pdf. The sample plots were established in ecologically homogeneous areas. The

plots consisted of a 10-m radius ecosystem plot and a 5.64-m (0.01 ha) radius site index plot (occasionally, other plot sizes were sampled) that was centred on the ecosystem plot. The site series of the ecosystem plot was assessed using the procedures published by Luttmerding et al. (1990). The height and breast height age of the site tree(s) for each species in the plot were measured. The site trees were selected based on their height growth being indicative of the productivity of the site. The sampling protocols list the characteristics that the site trees must have to reflect the productivity of the site.

The SIA data were collected on a project-by-project basis; consequently, the objectives and sampling protocols differed from project to project. In general, though, the plots were randomly established in target areas (usually younger managed stands of the target species) in five subplot clusters (one subplot at the sample point and four subplots in the cardinal directions). In each subplot, the site trees were identified and measured as per SIBEC protocols, and some biophysical attributes such as slope, aspect, and elevation were also measured.

METHODS

The species, height, and breast height age data were used to estimate site index with the SiteTools software (British Columbia Ministry of Forests and Range 2001). The site indices were averaged by species and plot (for the SIBEC data) or cluster of subplots (for the SIA data). Climate variables were predicted from latitude, longitude, and elevation using the ClimateWNA model (Wang et al. 2011). Table 1 shows the 20 annual climate variables predicted by ClimateWNA. Along with slope (%), aspect (degrees, with 0/360 being north), elevation (m), and biogeoclimatic zone, the climate variables are potential predictors of site index in the biophysical model. The following transformation was applied to aspect for the reasons outlined by Beers et al. (1966): cos(aspect-45). Not all records were complete; some lacked slope, aspect, elevation, and latitude/longitude. Only records with all these attributes were included in the biophysical modelling process.

A biophysical model was developed for the following species: trembling aspen (*Populus tremuloides*; species code At), amabilis fir (*Abies amabilis*; Ba), subalpine fir (*Abies lasiocarpa*; Bl), western redcedar (*Thuja plicata*; Cw, coastal and interior), paper birch (*Betula papyrifera*; Ep), Douglas-fir (*Pseudotsuga menziesii*; Fd, coastal and interior), western hemlock (*Tsuga heterophylla*; Hw, coastal and interior), western larch (*Larix occidentalis*; Lw), lodgepole pine (*Pinus contorta*; Pl), ponderosa pine (*Pinus ponderosa*; Py), black spruce (*Picea mariana*; Sb), Engelmann spruce (*Picea engelmannii*; Se), Sitka spruce (*Picea sitchensis*; Ss), white spruce (*Picea glauca*; Sw), and interior spruce (either white spruce, Engelmann spruce, or their cross [these species are commonly not differentiated in the interior of the province]; Sx). For Cw, Fd, and Hw, different models were developed for the coast and the interior. Coastal plots were from the Coastal Western Hemlock (CWH) or Coastal Douglas-fir (CDF) biogeoclimatic zones. The coding for spruce followed the conventions for the SIBEC model: if the spruce was coastal, it was coded as Ss; if the spruce was coded as Sb then it was Sb; if the spruce was in

TABLE 1 *Annual climate variables predicted by ClimateWNA*

Variable	Acronym/ Initialism	Units
Mean annual temperature	MAT	°C
Mean coldest month temperature	MCMT	°C
Mean warmest month temperature	MWMT	°C
Continentality (MWMT–MCMT)	TD	°C
Mean annual precipitation	MAP	mm
Mean summer (May–September) precipitation	MSP	mm
Annual heat to moisture index	AHM	°C mm-1
Summer (May–September) heat to moisture index	SHM	°C mm-1
Degree-days below 0°C	DD<0	°C days
Degree-days above 5°C	DD>5	°C days
Degree-days below 18°C	DD<18	°C days
Degree-days above 18°C	DD>18	°C days
Number of frost-free days	NFFD	days
Frost-free period	FFP	days
Beginning of frost-free period	bFFP	Julian date
End of frost-free period	eFFP	Julian date
Extreme minimum temperature of a 30-year normal period	EMT	°C
Precipitation as snow	PAS	mm
Reference atmospheric demand	Eref	mm
Climatic moisture deficit	CMD	mm

the Boreal Black and White Spruce (BWBS) zone and was not Sb, it was coded as Sw; if the spruce was in the Engelmann Spruce–Subalpine Fir (ESSF) zone and was not coded as Sb, it was coded as Se; otherwise if the spruce was not coded as Sb, it was coded as Sx.

The biophysical site index model was assumed to be linear with biogeoclimatic zone, slope, aspect, elevation, and the 20 climate variables in Table 1 as potential predictor variables. A plot of site index versus the predictor variables by species showed that transformations of the predictor variables (e.g., squaring them) were not needed. Variable selection proceeded by first fitting the model with all variables except biogeoclimatic zone using the STEPWISE method in procedure REG (SAS Institute Inc. 2004). This identified the significant predictor variables. The model was then refit in procedure REG using all the significant predictor variables with the VIF, TOL, and COLLIN options to obtain multicollinearity diagnostics.[1] The VIF option outputs the variance inflation factors, TOL outputs the tolerances, and COLLIN outputs the eigenvalues, condition numbers, and variance proportions (Sen and Srivastava 1990; SAS Institute Inc. 2004). Variables that showed high multicollinearity

1 Multicollinearity will likely be a problem when analyzing climate variables in a linear model (Nigh et al. 2004) because most of the variables are derived from the same data — that is, daily precipitation and/or temperature. Multicollinearity occurs when two or more predictor variables are closely related to each other (Sen and Srivastava 1990). For example, the variables TD, MWMT, and MCMT in Table 1 are highly correlated (TD = MWMT – MCMT). Because of the relationship between these three variables, it is not possible to include all of them in a linear regression model since the design matrix will be singular and a unique inverse cannot be found. A similar situation exists with FFP, bFFP, and eFFP. Other combinations of climate variables in Table 1 can result in near singularities, which is equally problematic.

but contributed little to the fit of the model based on the mean squared error (MSE) were deleted from the model. Interpreting the multicollinearity statistics is subjective and open to debate. In general, the guidelines presented by Sen and Srivastava (1990) were used. This process resulted in a set of significant predictor variables that were not correlated enough to cause problems due to multicollinearity. A final fitting was done using procedure GLM with the identified predictor variables from the previous step and biogeoclimatic zone in the model. If the species occurred in only one zone, for example Sw in the BWBS zone, or zone was not a significant predictor of site index, then the final fitting was done in procedure GLM without zone in the model. Adding zone to the model sometimes caused some of the climate variables to become non-significant. In these cases, the non-significant variables were deleted during the final model fitting stage.

The analysis was completed by producing q-q plots of the residuals, a plot of measured site index versus predicted site index, and a plot of the residuals against the predicted site indices. The plots helped in assessing whether the residuals were normally distributed and homoscedastic, and gave some indication of the fit of the model (Sen and Srivastava 1990). Partial residual plots were also produced for each variable in the model (Mason et al. 1989, p. 536). Those plots showed the relationship between an independent variable and the response variable given that other independent variables were also in the model. They were useful for determining the linear and nonlinear (if present) effect of the variable.

The derived biophysical model was compared to a benchmark using the MSE statistic. Bias was not considered as a statistic for comparison because the models were linear with an intercept. This resulted in the model residuals having a mean of 0 (Sen and Srivastava 1990), which indicated that the models were unbiased. The obvious first choice for a benchmark was the SIBEC model. Since SIBEC is essentially a suite of hundreds of models (one model for every species and site series combination), each with a different and unknown MSE, it would be necessary to refit all the models in order to calculate the MSE. A simpler alternative to the SIBEC model was to develop a benchmark model using biogeoclimatic zone, soil moisture regime (SMR) (Meidinger and Pojar 1991), soil nutrient regime (SNR) (Meidinger and Pojar 1991), and elevation as predictor variables. The analysis was done with procedure MIXED in SAS (SAS Institute Inc. 2004), with zone, SMR, and SNR as categorical variables and elevation as a continuous variable. Only the SIBEC data were used for this analysis since the SIA data did not have reliable SMR and SNR data. Note that SMR is a relative measure of moisture (Banner et al. 1993). Actual soil moisture regime was not available, although it could have been derived from biogeoclimatic unit and SMR. This was not done because the focus of the project was not the benchmark model, and SMR was still useful for predicting site index.

RESULTS

Table 2 presents the results of the biophysical model and the benchmark model. Only the MSE statistic is reported for the benchmark model and is used only to compare the benchmark to the biophysical model. The q-q plots

did not show any significant deviations from normality in the residuals. The plots of the residuals against the predicted site indices did not show evidence of heteroscedasticity. The plots of actual site index versus predicted site index did not reveal any lack of fit, although there was substantial variation around the 1:1 line for some species, which is also indicated by the larger MSEs in Table 2. The partial residual plots indicated that all variables in all models had a linear effect, except for DDGT18 for coastal western redcedar. The plot for this variable suggested that DDGT18 had a quadratic effect, so DDGT18 × DDGT18 was included in the model and was significant at $\alpha = 0.05$. Figure 1 shows examples of partial residual plots for interior Douglas-fir. The regression of the partial residual against the independent variable has an intercept of 0 and a slope equal to the slope of the variable in the biophysical model (Mason et al. 1989, p. 537). This line is reproduced on the partial residual plots.

TABLE 2 *Statistics from the analysis of the biophysical site index model, including the estimated parameters, mean squared error (MSE), number of observations, R^2, the p-value of the overall model, and, for comparison, the MSE of the benchmark model. All estimated parameters are significant at $\alpha = 0.05$.*

Species	Variable[a]	BEC zone[b]	Parameter estimates	MSE	Benchmark MSE	No. of obs	R^2	p
Trembling aspen	Intercept	BWBS, ICH, IDF, MS, SBPS, SBS	-0.7707	15.70	15.63	320	0.33	<0.0001
	AHM		-0.3195					
	Aspect		1.1514					
	E_{ref}		0.0233					
	NFFD		0.0947					
	Slope		-0.0575					
Amabilis fir	Intercept	CWH	23.0004	14.82	15.73	326	0.43	<0.0001
	AHM		-0.3121					
	Aspect		0.5723					
	Elevation		-0.0085					
	MWMT		0.5885					
Subalpine fir	Intercept	BWBS	11.6633	13.13	14.03	1085	0.22	<0.0001
		ESSF	8.8158					
		ICH	9.6597					
		IDF	14.7657					
		MS	10.3213					
		SBPS	8.2783					
		SBS	9.2568					
	DDGT18		-0.1237					
	Elevation		-0.0032					
	E_{ref}		0.0318					
	SHM		-0.0906					
Western redcedar (coast)	Intercept	CWH	-7.8832	18.86	11.63	375	0.28	<0.0001
	DDGT5		-0.0255					
	DDGT18		0.0677					
	Elevation		-0.0061					
	E_{ref}		0.0184					
	MAP		0.0013					
	MWMT		3.4335					
	Slope		0.0254					

TABLE 2 *Continued*

Species	Variable[a]	BEC zone[b]	Parameter estimates	MSE	Benchmark MSE	No. of obs	R^2	p
Western redcedar (interior)	Intercept	ICH, IDF, MS	33.3545	10.53	9.89	137	0.12	0.0002
	MAP		0.0034					
	TD		-0.8152					
Paper birch	Intercept	BWBS, ICH, IDF, MS, SBS	9.7865	10.83	8.52	124	0.13	0.0003
	NFFD		0.0634					
	Slope		-0.0674					
Douglas-fir (coast)	Intercept	CDF, CWH	33.5417	34.29	20.47	619	0.13	<0.0001
	Elevation		-0.0078					
	MSP		0.0059					
	Slope		-0.0210					
Douglas-fir (interior)	Intercept	ESSF	40.9130	14.64	13.34	1201	0.37	<0.0001
		ICH	44.1200					
		IDF	41.0985					
		MS	41.8979					
		SBPS	40.3106					
		SBS	41.5649					
	AHM		-0.2277					
	Aspect		0.4755					
	Elevation		-0.0049					
	EMT		0.2832					
	Slope		-0.0256					
Western hemlock (coastal)	Intercept	CWH	8.1749	30.84	20.04	1008	0.11	<0.0001
	AHM		-0.3497					
	Elevation		-0.0033					
	MCMT		1.4812					
	Slope		0.0187					
	TD		1.3640					
Western hemlock (interior)	Intercept	ICH	20.8763	15.02	16.41	189	0.15	<0.0001
	Elevation		-0.0050					
	E_{ref}		0.0146					
	SHM		-0.1300					
Western larch	Intercept	ESSF	33.1315	12.39	11.77	226	0.17	<0.0001
		ICH	35.3470					
		IDF	34.1027					
		MS	33.1514					
	AHM		-0.2298					
	DDLT0		-0.0087					
Lodgepole pine	Intercept	BWBS	10.0465	8.87	9.78	2551	0.32	<0.0001
		ESSF	10.2552					
		ICH	11.7969					
		IDF	10.7090					
		MS	11.1451					
		SBPS	10.1015					
		SBS	11.2656					
	AHM		-0.0879					
	Aspect		0.2629					
	CMD		-0.0077					
	DDGT5		0.0069					
	DDGT18		-0.0332					

TABLE 2 *Concluded*

Species	Variable[a]	BEC zone[b]	Parameter estimates	MSE	Benchmark MSE	No. of obs	R^2	p
Lodgepole pine (continued)	Elevation		-0.0018					
	E_{ref}		0.0130					
	Slope		-0.0147					
Ponderosa pine	Intercept	BG, ICH, IDF, PP	35.5385	11.72	12.67	109	0.30	<0.0001
	EMT		0.6367					
	PAS		0.0284					
	Slope		-0.0751					
Black spruce	Intercept	BWBS	13.2663	6.19	4.82	105	0.18	0.0001
		SBPS	17.0151					
		SBS	14.7391					
	Elevation		-0.0041					
Engelmann spruce	Intercept	ESSF	-4.5938	14.93	16.66	424	0.28	<0.0001
	AHM		0.3155					
	Elevation		-0.0032					
	E_{ref}		0.0619					
	MSP		0.0258					
	MWMT		-1.3636					
Sitka spruce	Intercept	CWH	24.4576	31.46	29.04	423	0.17	<0.0001
	Elevation		-0.0093					
	MAP		0.0019					
White spruce	Intercept	BWBS	42.3204	8.98	9.05	93	0.19	0.0003
	DDGT5		-0.0085					
	MSP		-0.0408					
	Slope		-0.0990					
Interior spruce	Intercept	ICH	12.5755	15.07	15.02	1820	0.21	<0.0001
		IDF	10.0995					
		MS	11.5865					
		SBPS	9.8511					
		SBS	10.7449					
	DDGT5		0.0063					
	Elevation		-0.0017					
	MSP		0.0130					

a AHM: annual heat to moisture index; CMD: climatic moisture deficit; DDGT5: degree-days above 5°C; DDLT0: degree-days below 0°C; DDGT18: degree-days above 18°C; EMT: extreme minimum temperature of a 30-year normal period; E_{ref}: reference atmospheric demand; MAP: mean annual precipitation; MCMT: mean coldest month temperature; MSP: mean summer (May–September) precipitation; MWMT: mean warmest month temperature; NFFD: number of frost-free days; PAS: precipitation as snow; SHM: summer (May–September) heat to moisture index; TD: Continentality (MWMT – mean coldest month temperature)

b BG: Bunchgrass; BWBS: Boreal White and Black Spruce; CDF: Coastal Douglas-fir; CWH: Coastal Western Hemlock; ESSF: Engelmann Spruce–Subalpine Fir; ICH: Interior Cedar-Hemlock; IDF: Interior Douglas-fir; MS: Montane Spruce; PP: Ponderosa Pine; SBPS: Sub-Boreal Pine–Spruce; SBS: Sub-Boreal Spruce

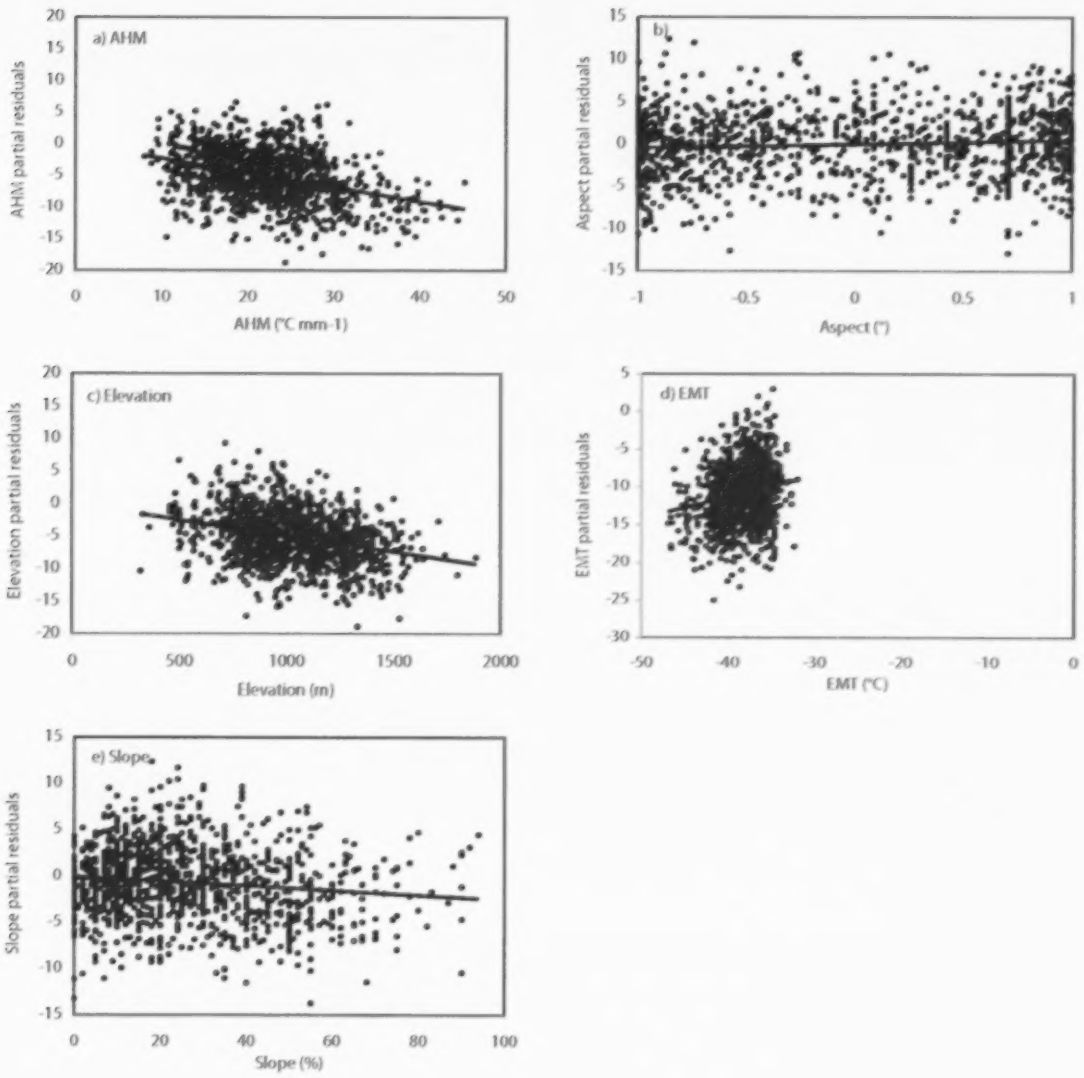

FIGURE 1 *Partial residual plots with their regression line for the variables in the biophysical model for interior Douglas-fir ([a] Annual heat to moisture index [AHM], [b] Aspect, [c] Elevation, [d] Extreme minimum temperature of a 30-year normal period [EMT], [e] Slope).*

DISCUSSION

This research provides a suite of 18 models for the 15 commercially important tree species that were analyzed. These models can be used to estimate site index in biogeoclimatic zones specific to each species (Table 2 shows the zones that are specific to each species). The predictor variables for these models, in order from most common to least common, are elevation (12 occurrences), slope (9 occurrences), AHM (7 occurrences), E_{ref} and biogeoclimatic zone (6 occurrences each), aspect, DDGT5, and MSP (4 occur-

rences each), DDGT18, MAP, and MWMT (3 occurrences each), EMT, NFFD, SHM, and TD (2 occurrences each), and CMD, DDLTO, MCMT, and PAS (1 occurrence each).

In comparison to the benchmark model, the biophysical model, for the most part, performs equally well when the MSE is the comparator. The biophysical model had an MSE that was significantly higher (> 2.0) than the benchmark model for the coastal species Cw, Fd, Hw, and Ss, and the interior species Ep. The difference in the MSE between the two models for these species ranges from 2.31 to 13.82.

The biophysical model is designed to use predictor variables that are readily available. The zones can be obtained from the BEC maps in the B.C. Geographic Warehouse (BCGW)(https://apps.gov.bc.ca/pub/dwds/home.so). Elevation information is available through GeoBC (//archive.ilmb.gov.bc.ca/crgb/products/#geospatial), from which slope and aspect can be derived. The climate variables are predicted from ClimateWNA (Wang et al. 2011) using elevation and location data. ClimateWNA is available at www.genetics.forestry.ubc.ca/cfcg/ClimateWNA/ClimateWNA.html. The biophysical site index model is being implemented in a site index GIS layer for the BCGW. Other sources of site index data will also be included in the layer, although, besides the biophysical model, currently only the SIBEC with PEM/TEM are being implemented.

The biophysical site index model will predict a site index for any location and species, provided the location is in a BEC zone where there are data for the species (see Table 2). However, the range of the species may not extend across the whole BEC zone. For example, coastal Douglas-fir grows mainly in the southern part of the CWH zone (Klinka et al. 2000). Therefore, users need to be mindful of the range of the species when applying the model.

The model is designed for strategic, as opposed to operational, applications. When used in site-specific (operational) applications, the predicted site indices could have large errors. Based on the data analysis, the errors are generally normally distributed with a mean of 0 and a variance given by the MSE in Table 2. Therefore, as a rough guide, 95% of the errors in site index estimates on a site-specific basis will be within twice the square root of the MSE of the true site index.

CONCLUSION

It was possible to construct a suite of biophysical site index models from biogeoclimatic zone, slope, aspect, elevation, and climate variables that give reasonable predictions of site index for 15 commercially important tree species in British Columbia. When compared to a suite of benchmark models, the accuracy of the biophysical model is about the same except for five models, which performed somewhat worse to substantially worse when the comparison was based on the MSE. The site index biophysical model will be included in a site index GIS layer to assist in making site index estimates widely available in British Columbia.

LITERATURE CITED

Banner, A., W. MacKenzie, S. Haeussler, S. Thomson, J. Pojar, and R. Trowbridge. 1993. A field guide to site identification and interpretation for the Prince Rupert Forest Region. B.C. Min. For., Victoria, B.C. Land Manag. Handb. 26.

Beers, T.W., P.E. Dress, and L.C. Wensel. 1966. Aspect transformation in site productivity research. J. For. 64:691–692.

British Columbia Ministry of Environment. 2012. Ecology. www.env.gov.bc.ca/ecology/index.html (Accessed Jan. 4, 2012).

British Columbia Ministry of Forests and Range. 2001. SiteTools. www.for.gov.bc.ca/hre/sitetool/ (Accessed Jan. 10, 2012).

———. 2011. Site index estimates by site series (SIBEC) – second approximation. www.for.gov.bc.ca/hre/sibec/ (Accessed Jan. 3, 2012).

Klinka, K., J. Worrall, L. Skoda, and P. Varga. 2000. The distribution and synopsis of ecological and silvical characteristics of tree species of British Columbia's forests. Can. Cartographics Ltd., Coquitlam, B.C.

Luttmerding, H.A., D.A Demarchi, E.C. Lea, D.V. Meidinger, and T. Vold. 1990. Describing ecosystems in the field. 2nd ed. B.C. Min. Environ., Lands and Parks and B.C. Min. For., Victoria, B.C. MOE Manual 11.

Mah, S. and G.D. Nigh. 2003. SIBEC site index estimates in support of forest management in British Columbia. B.C. Min. For., Res. Br., Victoria, B.C. Tech. Rep. 004.

Mason, R.L., R.F. Gunst, and J.L. Hess. 1989. Statistical design and analysis of experiments with applications to engineering and science. John Wiley & Sons, Toronto, Ont.

Meidinger, D. and J. Pojar. 1991. Ecosystems of British Columbia. B.C. Min. For., Res. Br., Victoria, B.C. Spec. Rep. 6.

Nigh, G.D., C.C. Ying, and H. Qian. 2004. Climate and productivity of major conifer species in the interior of British Columbia, Canada. For. Sci. 50:659–671.

SAS Institute Inc. 2004. SAS OnlineDoc® 9.1.3. SAS Institute Inc., Cary, N.C.

Sen, A. and M. Srivastava. 1990. Regression analysis: theory, methods, and applications. Springer Verlag New York Inc., New York, N.Y.

Wang, T., A. Hamman, D.L. Spittlehouse, and T.Q. Murdoch. 2011. ClimateWNA—high-resolution spatial climate data for western North America. J. Appl. Meteorol. Climatol. Early online release: DOI: 10.1175/JAMC-D-11-043.1.